Sextant Sighting Performance in the Ames Midcourse Navigation and Guidance Simulator

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The Ames Research Center is studying the role of the crew in the navigation, guidance, and control for the midcourse phase of manned space missions. In pursuit of these investigations, a lunar midcourse navigation and guidance simulator has been constructed at Ames.

This device presents, for one thing, a controlled visual task to the human operator in a relatively realistic manner. Our principal purpose in discussing it here is to let you know that it exists and to let you form some idea of its capabilities as a research device for visual problems. To achieve this purpose we will briefly describe the major features of the simulator and the conduct of an exploratory study of sextant sighting performance in the simulated task environment.

The visual scene is a 25° portion of the sky, including a simulated moon which is translatable in accordance with long-period vehicle-moon relative motions for a typical trajectory.

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Figure 1 shows the moving cab mounted on an air bearing. The cab is driven by an on-board cold gas system. The air-bearing support is a portion of a 105-inch sphere which allows rotational motion up to $\pm 10^{\circ}$ in pitch and roll and $\pm 90^{\circ}$ in yaw. The on-board cold gas control system has been successfully used to stabilize the cab both manually and automatically during optical sighting tasks. It has also provided limit cycle operation. insert Fig. 1

Figure 2 depicts the celestial visual scene that has been simulated in the midcourse simulator. The direct optical planetarium approach to visual scene generation has been utilized. The visual scene, located about 40 feet from the viewing point, is composed of 64 stars which are contained in the 25° segment of the sky surrounding the moon. This segment results from the choice of a specific trajectory which is taken as being typical of several possible lunar trajectories. insert Fig. 2

The simulated stars are simply 0.005-inch diameter holes in the end of a tube lighted by a grain-of-wheat lamp. They have a subtended angle of about 2 arc seconds and maintain their relative positions within ±5 arc seconds for as long as 8 hours. Unfortunately, the direct optical planetarium is subject to optical parallax due to the finite distance between the light source and the viewer. To minimize the errors in angular measurements due to parallax, four of the star images were collimated by means of 6-inch parabolic mirrors with small light sources at the focus to represent the stars. Figure 3 is a picture of the collimating device. The images produced in the parabolic mirrors, when viewed from the simulator cab, appear to be at infinity and have the same direction when viewed anywhere within the viewing limits of the parabolic mirrors. To extend the viewing area these collimated stars are being fitted with insert Fig. 3

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12-inch parabolic mirrors. Use of the larger mirror will of course extend the magnitude of rotational oscillations which may be employed in research on the effects of motion on sighting accuracy.

This very brief description of the simulation facility is taken from an unpublished paper by Donald Smith of Ames Research Center.

Now, the research with this facility concerns mainly the identification and verification of performance capabilities of the human operator as an active participant in the positive fixing and guidance of the vehicle during translunar or midcourse flight. This use of the simulator rests upon the conviction that man can be a useful adjunct to, or replacement for, fully automatic primary systems. His capabilities in this task environment thus must be fully explored and delineated (1). One of the important tasks which will concern the astronaut is that of obtaining navigation information. For the moment we are investigating manual sextant sighting performance as a possible minimum manual system for gathering navigation data. Later this task will be integrated with the larger task of inputting the data to the on-board computer and ultimately with the broader task context of vehicle alinement, sighting, computation, and velocity correction. Our immediate larger goal is to simulate up to an 8-hour segment of the midcourse phase of the translunar trajectory.

I would like now to discuss briefly this first task element - sextant sighting - which has been our initial concern.

There have been many manual navigation schemes proposed in the literature for finding one's way about in the solar system (2,3,5,7,8,11). These are generally of two kinds:

(1) Extensions of conventional celestial navigation techniques for the explicit, point-by-point determination of present and future position.

(2) Implicit guidance through the determination of the elements of the orbit and their departure from or agreement with a reference orbit which has been predetermined to intersect the coordinates of the desired target point in space.

Both of these methods involve considerable mathematical computation, but, each, in most cases, depends first upon the seemingly simple task of measuring an angle with an optical sighting device. In marine and air navigation the accuracy of the celestial fix depends largely upon the measurement of the altitude of the body of interest above the natural sea horizon or the bubble horizon. In navigation in space, several kinds of angles may be of interest. Some of these are:

(1) The angle between the line of sight of a lunar or terrestrial or planetary landmark and a star.

(2) The angular extension of any of the planets, moon, or sun.

(3) The angle between a star and the limb of a planet, moon, or sun.

(4) The angle between the earth or moon and the vehicle centered horizon.

Since the marine sextant may be rotated through any angle to measure the angle between any two points of interest, this is the instrument we have been using. The bubble sextant is disqualified, of course, because of its dependence upon a gravitational field.

Specifically, we have had early access to the Navy Mark II Mod 0 hand-held sextant and have used it mainly because of its availability. This sextant has a 3 power scope and a 10° field of view. More recently we have come upon a modern sextant with interchangeable telescopes and this will be used in future studies.

It probably appears an audacious bit of romance to bring forward this time-honored device for evaluation against the precision requirements of space navigation. However, as an entrance point to the study of the fundamental sighting task its employment is inescapable and appears thus far to be quite fruitful. This is particularly true where it is desired to estimate relative accuracies under various sighting conditions and the inherent sextant errors bias only the determination of the true angle. The variance of the operator's sighted angles about their mean is the criterion measure for a given sighting session, and the change in this score with the conditions of the study is the experimental variable of interest.

Figure 4 is a photograph of the marine sextant we have been using. Insert Fig. 4 Its design, as for all sextants, is based upon the optical principle that the angle between the first and last directions of a ray of light that has undergone two reflections in the same plane is twice the angle that the two reflecting surfaces make with each other. Since the index arm is mechanically linked to the index mirror, the position of the arm on the limb indicates the angle between the two mirrors. The limb thus must be calibrated so that 0.5° of arc reads 1° of arc. Originally, the limb was a sixth of a circle, whence the name sextant; however, on modern sextants it is usually more than a sixth. There are several sources of error associated with this sextant. Some are due to mirror and telescope misalinement, others are due to eccentricity in the index arm, errors of graduation, and lack of parallelism between mirror and shade glasses (4).

Obviously, these are not highly accurate instruments in terms of error tolerances for space navigation. Position fixing on the open sea does not have stringent accuracy requirements nor does air navigation, necessarily, where critical corridors and terminal points are approached using other, more precise, techniques. In fact the German Hydrographic Office considers any sextant used for marine navigation purposes to be "free from errors for all practical use if the error goes up to twenty seconds" of arc. However, our theoreticians in space navigation and guidance employ an accuracy model of at most 10 seconds of arc in sighting performance in their analyses of navigation requirements (6,9,10).

The literature is not at all replete with controlled studies of sextant sighting accuracy. One study, in which a modified modern sextant was used, measured performance in sighting on actual celestial objects in the night sky (12). Two stars, a star and a planet, and a star and a moon crater were the targets. The sextant was fitted with a 6 × 30 telescope and it was mounted on a modified telescope mount. The micrometer vernier permitted angular interpolation to 3 arc seconds.

For the measurements of angle between two stars and a planet and a star, the standard deviation was of the order of 10 seconds of arc and for the star-crater pair it was of the order of 26 seconds of arc.

In our case, we used a hand-held sextant and a sextant gimbal mounted to the cab. Our telescope was three power with a 10° field of view. The vernier was readable to 6 seconds of arc with a dubious interpolation to 3 seconds of arc. Our interest was not, however, in the ascertainment of absolute sighting performance. We were trying to determine whether there was a difference in performance between the hand-held and the gimbaled sextant and also whether oscillatory motion affected performance to any great extent.

Accordingly, an arbitrary limit cycle function was programmed on an analog computer to drive the cab using the cold gas jet system. The limit cycle was restricted to the yaw axis, spurious motions in the other axes being damped to relatively small amplitudes. Three levels of rate were used: $1/2^{\circ}$ per second, 1° per second, and $1\text{-}1/2^{\circ}$ per second. A static condition was also included. The oscillations were contained within a $\pm 2^{\circ}$ band about the line bisecting the stars of interest. Two of our collimated stars, oriented in a near vertical position, were used as targets. The task was to measure the angle between these stars by superpositioning one star over the other in the sextant field of view.

For subjects, we employed three Air Force navigator instructors at nearby Mather Air Force Base, an advanced Air Force navigation school. Four professionals engaged in related studies at Ames Research Center were also included.

Since these investigations are still in process, it would be premature to present firm data at this time; however, some informal statements regarding apparent trends are in order.

Training is an important variable, at least for the task environment we are providing. We found that using two sighting sessions per day, a week or more was necessary to bring the subjects down to asymptote. Twenty-four sightings were taken in each session. This was true for the navigators, as well as for the professionals. For the navigators, transfer of training cannot be evaluated because of their lack of recent intensive use of their bubble sextants and the fundamental differences between that task and the present one. One of the major differences is due to the use with modern bubble sextants of manual or automatic integrating devices which allow for the averaging of a continuous sighting over a minute or two of time. The marine sextant is a single shot device and is so used in sea navigation. We noticed that our subjects regressed considerably in their learning after the intervention of a weekend. However, the losses were quickly recovered after some additional sessions. It is mandatory that the extent of retraining required after varying periods of nonpractice be determined if a strictly manual sighting scheme is to be seriously considered as an alternate mode for space navigation.

The cab motion does not appear to have a systematic effect on performance at the relatively large rates that we used. However, the effects of less discernible rates in both the limit cycle and the long period relative motions of the vehicle and bodies in the solar system have yet to be estimated.

Indications are that the gimbaled sextant has a slight edge, in terms of accuracy, over the hand-held. The subjects preferred the gimbaled sextant, particularly after having had some experience with both types. However, this is not sufficient to qualify the gimbaled and disqualify the hand-held, the difference amounting to some 3 seconds of arc in standard deviation. This is not very much when it is known that the standard deviations for all subjects ranged from 5 seconds to 46 seconds with a mean of 22 seconds of arc.

The three power telescope may not be the best for most accurate performance. We tried the modern sextant with a 6 × 30 telescope and though there was considerable random motion in the two star targets due to hand tremor, performance was better. Since this determination was based on only a few subjects, we are going to investigate the contribution to performance of various telescope magnifications using the newer sextant.

In the process of defining the details of the task it becomes apparent that the visual processes involved require separate treatment for their investigation. Accordingly, plans are being made to assess matters such as the relation of visual acuity to performance; the effects of fatigue; the effects of reticle geometry such as cross hairs versus concentric circles versus gun-sight type displays; the variance of performance with varying geometries of celestial targets; the effects of varying contrasts in the field of view; and the effects of training, lack of practice, and retraining on all of these. These are general statements because they result from an initial judgment of what is important in sighting performance as identified in the simulated task environment. The opportunity to make these judgments is provided by the midcourse navigation and guidance simulator.

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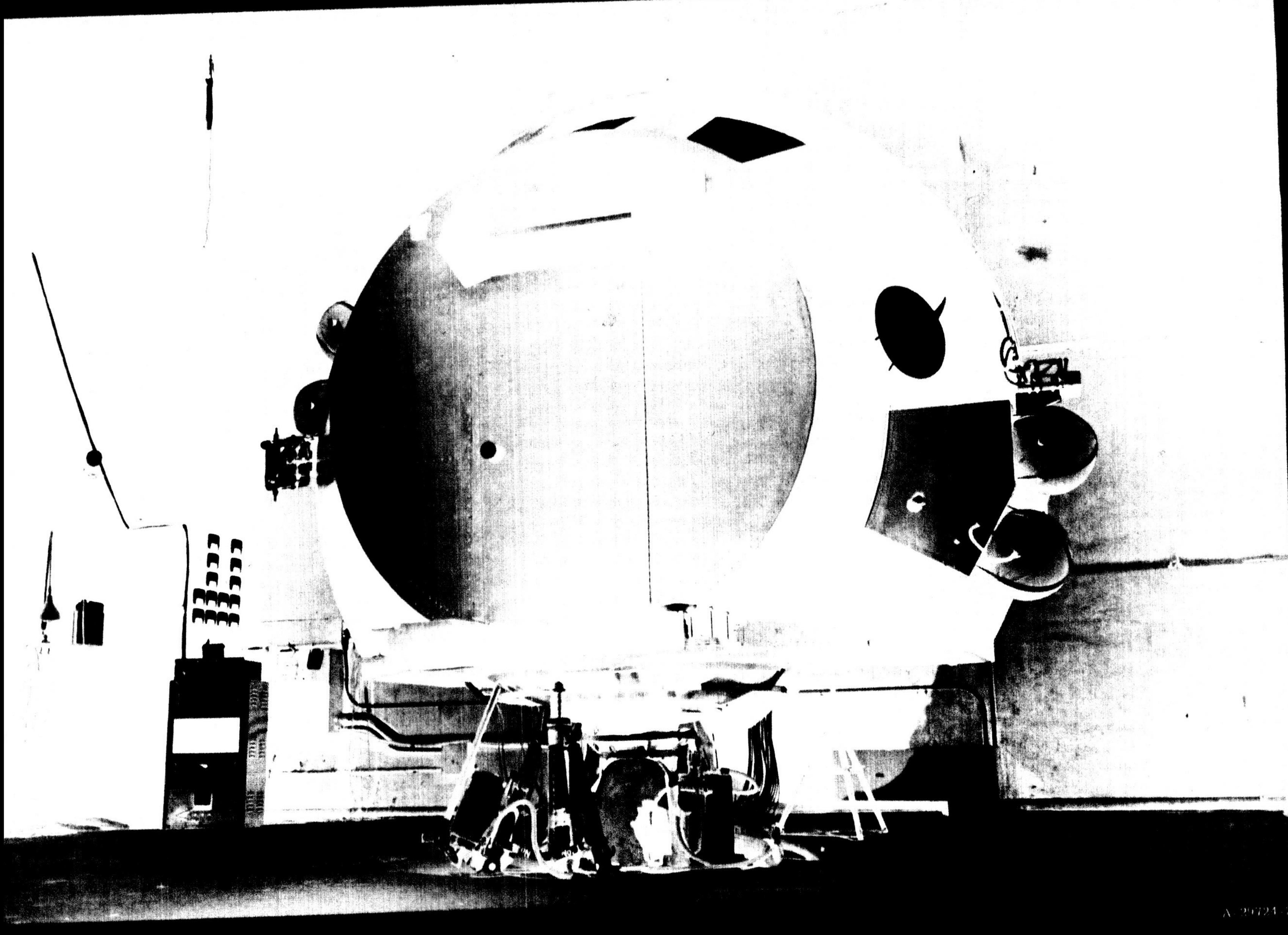
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Fig. 1

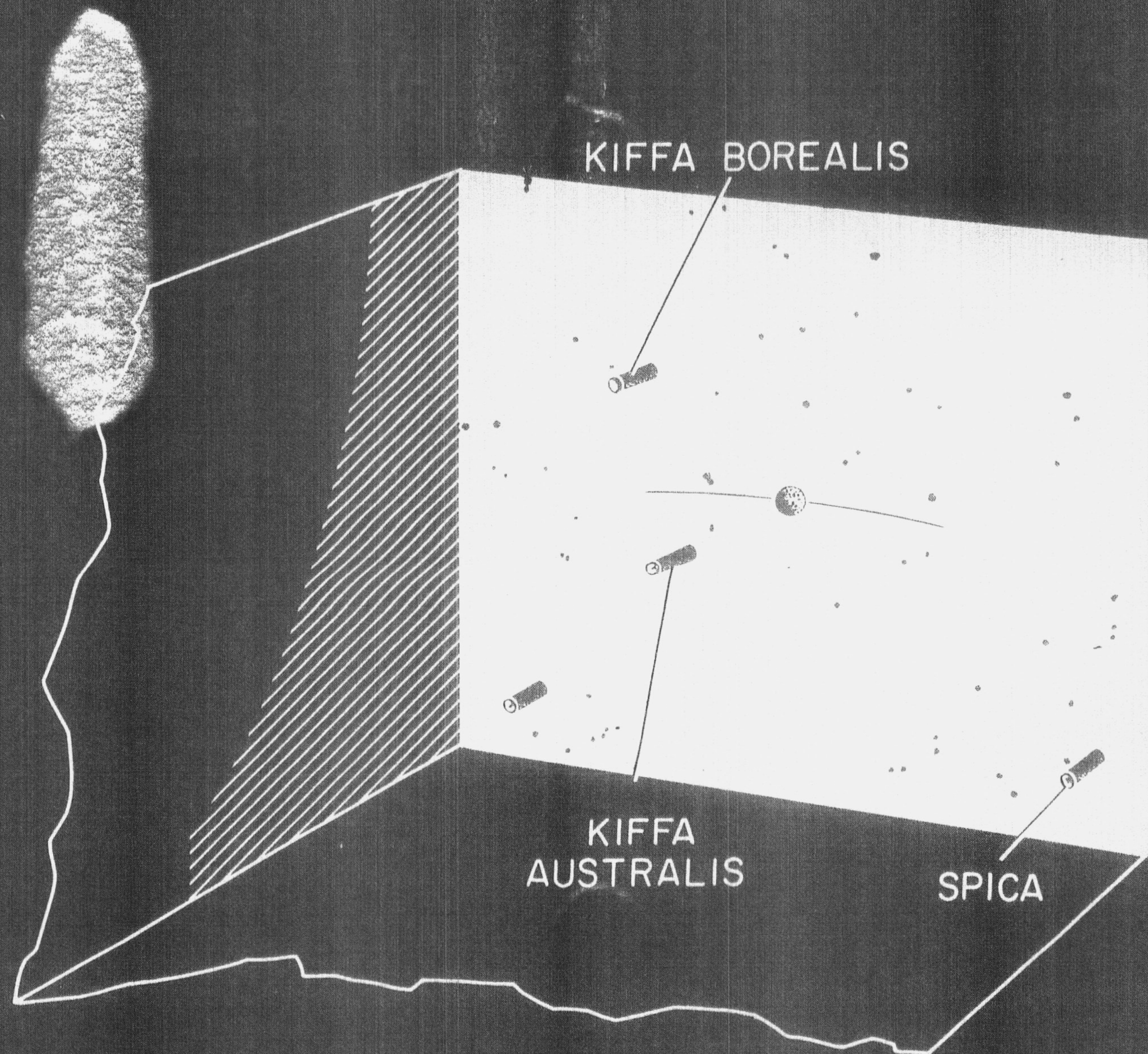

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Fig. 2

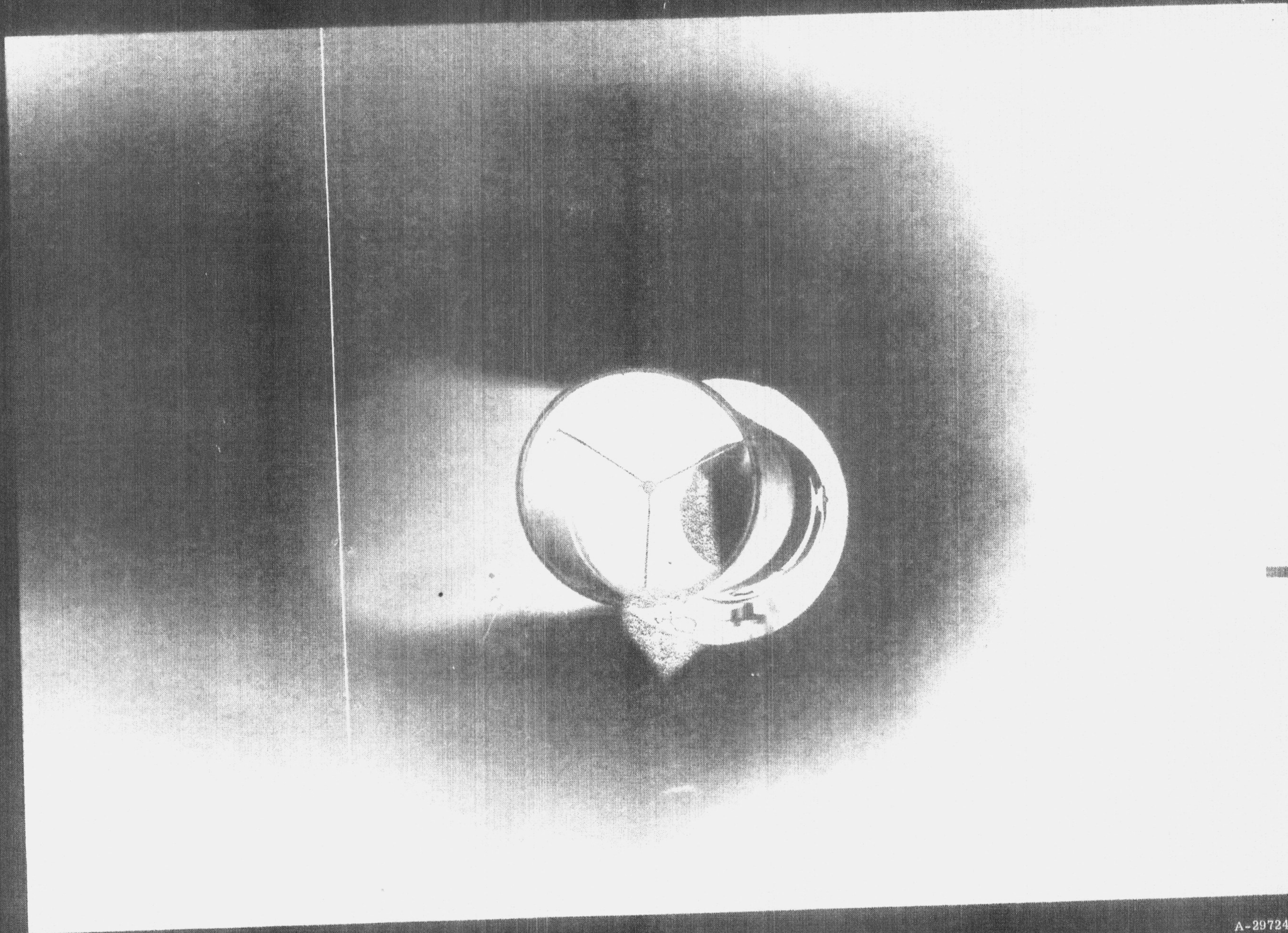

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Fig. 3

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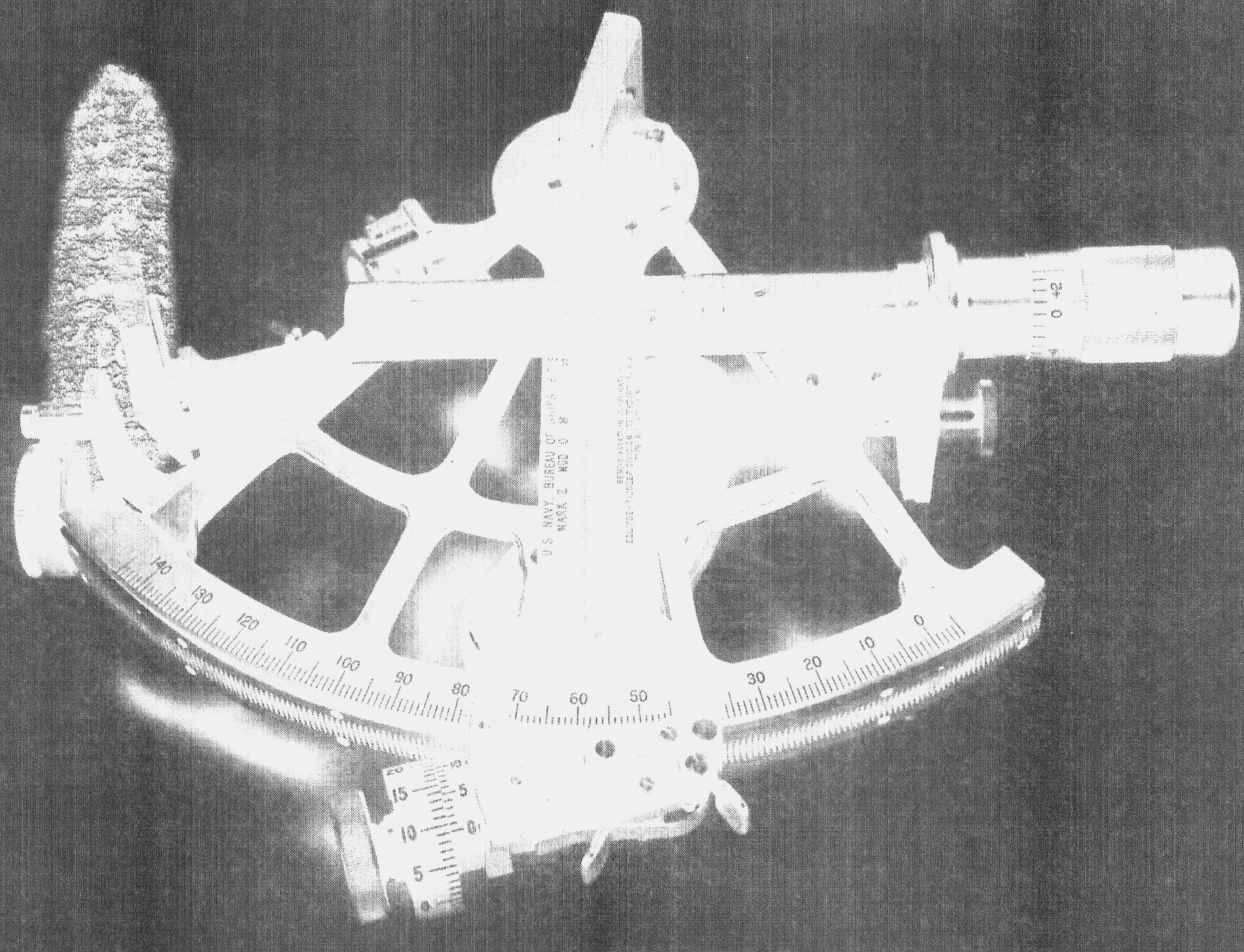

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Fig. 4

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